

Status of freshwater native mussels (Unionidae) in the Oklahoma section of the Verdigris River after introduction of the zebra mussel (*Dreissena polymorpha* Pallas, 1771)

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Abstract: The Verdigris River in Kansas and Oklahoma, USA once held a diverse native unionid mussel fauna although a number of these populations have declined in richness and abundance. There is recent evidence that populations of some species of unionid mussels are increasing in parts of the Verdigris River in Kansas, but no current data exist for Oklahoma. In addition, zebra mussels (*Dreissena polymorpha* Pallas, 1771) have been introduced into a major impoundment on the Verdigris River, Oologah Lake, and may further threaten mussel populations downstream from this reservoir. This study updates the distribution and abundance of native mussels in the Oklahoma portion of the Verdigris River upstream and downstream of Oologah Lake, and documents the current distribution of zebra mussels in this region. Thirty-one sites were sampled and a significant increase in species richness and abundance of native mussels was observed as compared to a 1997 study. Two species of special interest, *Cyprogenia aberti* (Conrad, 1850) and *Quadrula cylindrica* (Say, 1817), were found. Zebra mussels were not found at sites upstream of Oologah Lake but were present at every downstream site. In September 2006, zebra mussel byssal threads were observed on shells of a number of native mussels downstream from Oologah Lake, but unionid richness and abundance were not significantly different between sites above and below the reservoir.

Key words: invasive species, *Quadrula*, field survey, impoundment, semi-quantitative sampling

Freshwater mussels are considered one of the most imperiled groups of organisms in the world, with 70% of taxa within the family Unionidae considered of special concern or endangered (Bogan 1993, Strayer *et al.* 2004, Warren and Haag 2005, Jones *et al.* 2006). As for many other organisms experiencing population declines, loss of native mussels has been attributed to habitat alteration (Vaughn and Taylor 1999, Garner and McGregor 2001), point and non-point source pollution (Richter *et al.* 1997), and invasive species (Burlakova *et al.* 2000, Strayer *et al.* 2004).

The Verdigris River originates in the Flint Hills of southeastern Kansas (Schuster 1979) and flows south into Oklahoma where it joins the Arkansas River near Muskogee, Oklahoma. Historically, the Oklahoma portion of the Verdigris contained a diverse assemblage of native unionid mussels, with Isely (1924) describing this region as among the richest mussel faunas in the state. Since that time, significant portions of the river have been altered by impoundments and the lowest reaches have been dredged to create a navigation channel to the Arkansas River (USACE 2007). Agricultural activity and urban and industrial development have led to pollutant and sediment input, degrading water quality. Surveys conducted in both Kansas and Oklahoma in the 1990s indicated an overall decline in Verdigris River mussel populations compared to earlier studies (Obermeyer *et al.* 1997a, Vaughn 1998).

Interestingly, more recent surveys in Kansas have re-

ported increases in the densities of some unionid taxa. For example, Miller and Lynott (2006) report increases in the abundance of 10 mussel species in the Kansas portion of the Verdigris between 1991 and 2003, a change they attributed to improved habitat quality. The last mussel survey conducted in the Oklahoma portion of the Verdigris was by Vaughn (1998). In addition, zebra mussels (*Dreissena polymorpha* Pallas, 1771) were discovered in Oologah Lake, an impoundment of the Verdigris in Oklahoma, in the spring of 2003 (Laney 2005). While the distribution of *D. polymorpha* in the Verdigris River was largely unknown, the potential impact of these invasives on unionid mussels is well established (Ricciardi *et al.* 1996, Baker and Hornbach 1997, Schloesser *et al.* 2006). The objectives of this study were to survey the mussel communities in the Oklahoma portion of the Verdigris River to determine if increases similar to those in Kansas were occurring, to characterize the extent to which zebra mussels occur along this section of the Verdigris, and to gather preliminary data regarding their potential interaction with native mussels.

MATERIALS AND METHODS

Sampling locations in the Verdigris River were selected to correspond with sites previously sampled by Vaughn (1998). Sample sites were mostly riffle areas and mussel sur-

veys were conducted in runs immediately downstream of each riffle. Substrate ranged from loose gravel to cobble. Physical-chemical characteristics (temperature, dissolved oxygen, pH, and conductivity) were recorded using a Hydrolab Quanta multi-parameter probe (Hydrolab Corporation, Austin, Texas). Additionally, river water was collected in acid-washed polyethylene bottles and transported back to the laboratory on ice for determination of titratable alkalinity and hardness (APHA 1998).

Mussel surveys involved timed snorkel searches by two individuals. Surveys were conducted for at least 15 min (2 people $\times$ 15 min = 30 min total search time), with longer time intervals devoted to locations that contained greater areas of stable gravel substrate with good flow and low levels of fine sediment. Mussels were carefully removed from the substrate and placed in mesh bags. After each survey, mussels were sorted, measured to the nearest 0.01 mm maximum length using digital calipers (Fisher Scientific, Pittsburgh, Pennsylvania), and identified to species using keys by Cummings and Mayer (1992), Oesch (1995), and Couch (1997). Mussels were then carefully returned to the river throughout the search area. Live voucher specimens were not collected due to limited representatives of some species; however, digital photographs and relict shells from each sample site were deposited at the Ecotoxicology and Water Quality Research Laboratory at Oklahoma State University, Stillwater, Oklahoma.

Comparisons of mussel richness and abundance were made using 2-sample paired *t*-test for means ($\alpha = 0.05$) performed with SigmaStat version 3.1 (Systat Software Inc., San Jose, California). Regression coefficients and elevation of richness versus log-transformed abundance curves were generated for the present study and that conducted by Vaughn (1998) and were compared using *t*-tests at $\alpha = 0.05$ (Zar 1999).

RESULTS

A total of 31 sites (20 above Oologah Lake and 11 below) were surveyed for mussels between July and October 2006. Sites above Oologah Lake started approx. 0.5 km after the Verdigris River crossed the Oklahoma-Kansas border and ended approx. 28

km above Oologah Lake. The section of river between the last upstream site and the reservoir was not surveyed because of a general lack of riverine mussel habitat as the river widens and becomes more lake-like. Sites below Oologah Lake were located 1-25 km below the Oologah Lake dam. Habitat beyond this point also was considered unsuitable due to dredging in the McClellan-Kerr Navigation Channel.

Temperature across all sites ranged between 20-35 °C, dissolved oxygen between 6.0-11.9 mg/L, pH between 6-8 standard units, alkalinity between 120-170 mg/L CaCO₃, and hardness between 112-156 mg/L as CaCO₃. Seventeen species of mussels were identified from the Verdigris River as a whole (Fig. 1), with *Quadrula metanevra* (Rafinesque, 1820) being most abundant and *Quadrula nodulata* (Rafinesque, 1820) the least. *Cyprogenia aberti* (Conrad, 1850), *Lampsilis teres* (Rafinesque, 1820), and *Lasmigona complanata* (Barnes, 1823) were found only in sites above Oologah Lake, while *Megaloniais nervosa* (Rafinesque, 1820), *Quadrula cylindrica* (Say, 1817), and *Q. nodulata* were found only at sites below the lake. Generally, abundant species were also the most widely distributed except for *Q. cylindrica* which was found only at three locations but was the sixth most abundant species (Fig. 2). Size-frequency distributions were developed

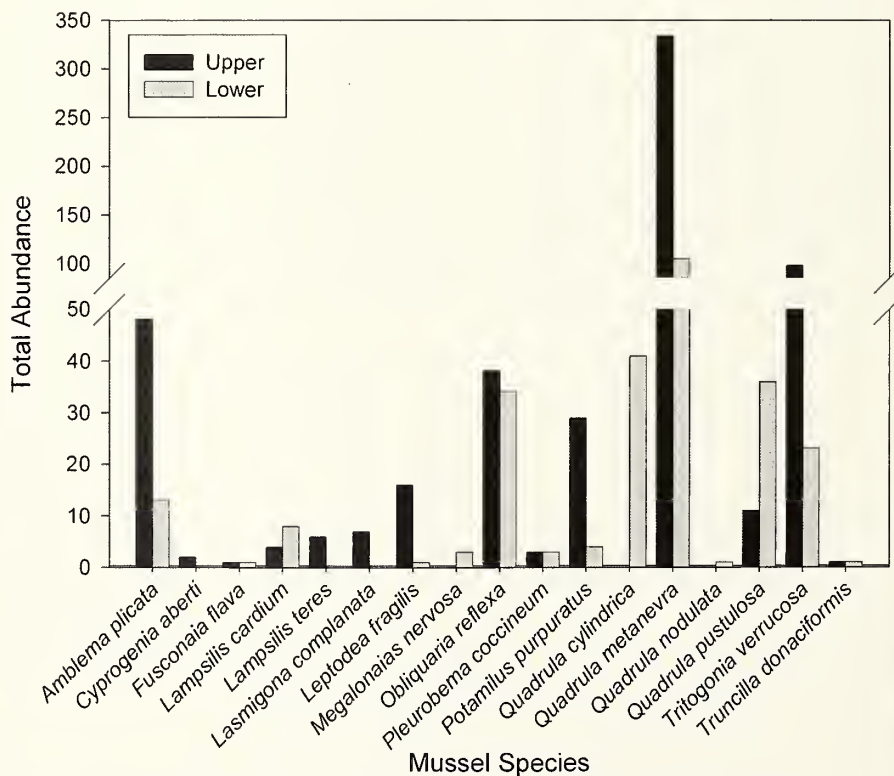


Figure 1. Abundance of native mussels (total number found) in the Verdigris River, Oklahoma, above (Upper) and below (Lower) Oologah Lake.

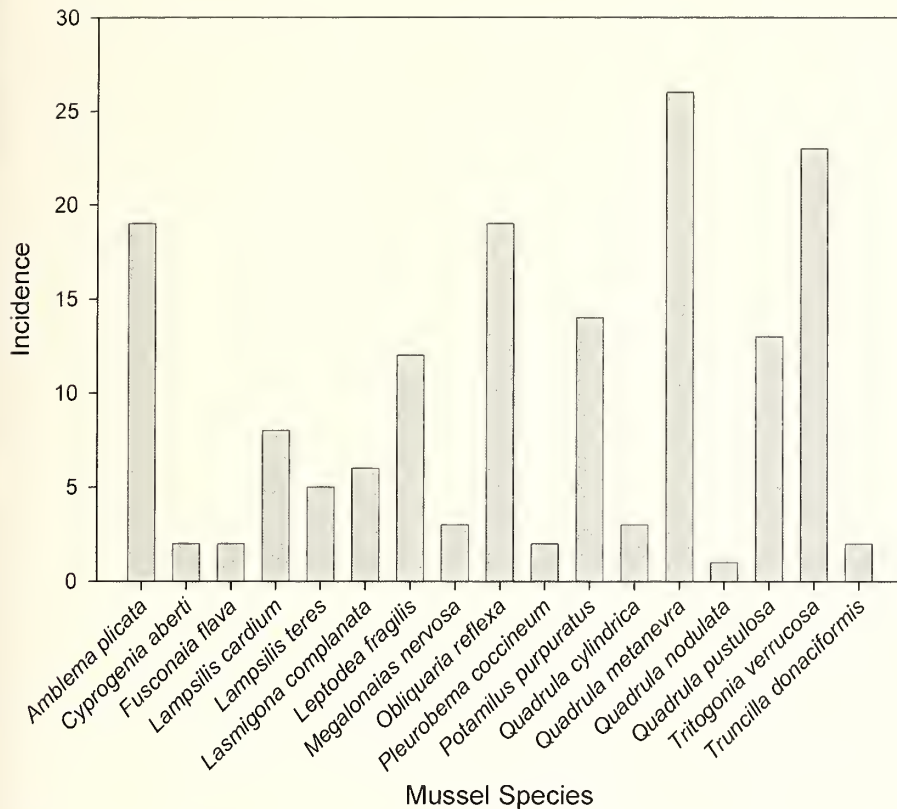


Figure 2. Incidence (number of sites at which a species occurred) of native mussels for the Verdigris River, Oklahoma. Maximum incidence = 31.

Table 1. Mean richness and abundance (#/h, mussels found per hour sampling effort) for sites within the Verdigris River, Oklahoma. Upper, sites above Oologah Lake; Lower, sites below the lake; All, all sites combined.

Sites	Mean richness	Mean #/h	N
Upper	5.60	39.31	20
Lower	4.36	35.66	11
All	5.16	38.01	31

for the four most abundant species, *Q. metanevra*, *Tritogonia verrucosa* (Rafinesque, 1820), *Obliquaria reflexa* (Rafinesque, 1820), and *Amblema plicata* (Say, 1817) (Fig. 3). The distributions for all four species were negatively skewed, indicating fewer small individuals than might be predicted given a normal distribution, with kurtosis values generally positive except for *O. reflexa* with a -0.74 value indicating a slightly more platykurtic (uniform) distribution.

Live mussels were found at all but 2 sites. Timed abundance estimates for sites with live mussels ranged from 3 to

156 mussels per hour (#/h) with a mean of 38 for all 31 sites (Table 1). Taxa richness ranged from 2 to 10 species per site with a mean of 5.2 species for all 31 sites combined.

No evidence of zebra mussels was found at any site above Oologah Lake; however, zebra mussels and byssal threads were found on substrate and unionid shells at every site below the lake. While many native mussels collected below the lake had byssal threads on the valves, few had live zebra mussels attached. In order to assess the potential impact of zebra mussels on native mussel community composition, species richness and abundance were estimated separately for sites above and below the lake. Sample locations above the lake had a mean richness of 5.6 species per site, and an abundance of 39.3/h (Table 1). Sites below Oologah Lake had a mean richness of 4.4 species per site with an abundance of 35.7/h (Table 1). There was no significant difference in overall mussel species richness or abundance between upstream and downstream sites ($P = 0.12$ and $P = 0.41$, respectively).

While no differences in mussel richness and abundance were apparent when sites were combined within upstream and downstream sections, a downstream longitudinal gradient in these parameters was apparent. Both mussel abundance ($r^2 = 0.697$, $N = 11$, $P = 0.001$) and species richness ($r^2 = 0.539$, $N = 11$, $P = 0.014$) were significantly positively associated with distance from the dam (Fig. 4). However, these analyses may be influenced by two downstream sites that had the greatest abundance of any of the sample locations. When these two sites are removed from the analyses, the longitudinal relationship is no longer significant (#/h: $r^2 = 0.31$, $N = 9$, $P = 0.120$; richness: $r^2 = 0.38$, $N = 9$, $P = 0.077$).

DISCUSSION

Sampling locations in the Verdigris River corresponded to a previous study (Vaughn 1998) to reassess the status of the native mussel community since the discovery of zebra mussels in Oologah Lake in June 2003. Vaughn (1998) identified 16 species of mussels, compared with 17 in this study.

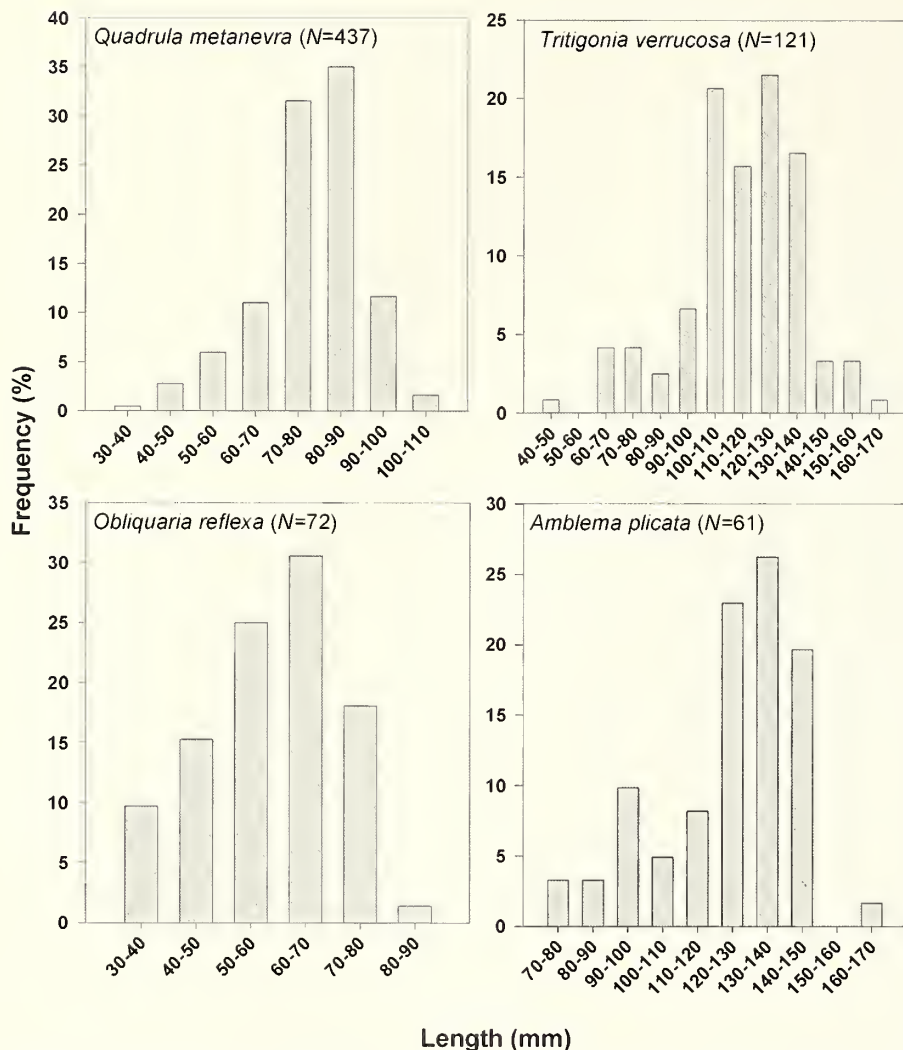


Figure 3. Size-frequency distributions for the four most abundant mussel species in the Verdigris River, Oklahoma. *N*, number of observations for that species.

While species composition was largely similar between the two surveys, *Potamilus ohioensis* (Rafinesque, 1820) and *Quadrula quadrula* (Rafinesque, 1820) were not found in 2006. In contrast, live *Cyprogenia aberti*, *Quadrula cylindrica*, and *Quadrula nodulata* were found in the 2006 survey while only relict shells of these species were found in the previous survey. Of these, *C. aberti* and *Q. cylindrica* are of particular interest because *C. aberti* was once thought extirpated from the state (Mather 1990, Serb 2006), and *Q. cylindrica* is a federal candidate for listing as an endangered species (David Martinez, pers. comm., U. S. Fish and Wildlife Service). Only 2 *C. aberti* were found, and both individuals were from sites near the Oklahoma-Kansas border. As abundance of this species has increased in the Kansas portion of the Verdigris (Miller and Lynott 2006), these upstream populations

may be responsible for the re-introduction into Oklahoma through mechanisms such as fish host dispersal or downstream transport of juveniles after detaching from the fish host (Morales *et al.* 2006).

While *Quadrula cylindrica* was the sixth most abundant species, it was found only in a short river section downstream from Oologah Lake, an area also infested with zebra mussels. Lee *et al.* (1998) and Berg *et al.* (2007) suggest host-fish vagility may explain unionid distribution patterns, with mussels that utilize fish hosts with greater home ranges typically showing greater abundance and distribution. The known fish hosts for *Q. cylindrica* include several species of *Notropis* (Yeager and Neves 1986), which have relatively small home ranges (Goforth and Foltz 1998). This characteristic of its fish host may explain the limited distribution of *Q. cylindrica* in the Verdigris.

Size-frequency distributions of the 4 most commonly encountered mussel species did not include individuals less than 30 mm in length (70 mm for *Amblema plicata*) although this may have been a sampling artifact as timed snorkel searches bias against encountering very small or particularly cryptic individuals (Hornbach and Deneka 1996, Obermeyer 1998, Metcalfe-Smith *et al.* 2000). Furthermore, juveniles frequently bury in the substrate, making

detection difficult using snorkel searches (Neves and Widlak 1987, Amyot and Downing 1991, Yeager *et al.* 1994, Sparks and Strayer 1998). Timed snorkel search techniques are, however, more commonly used for determining mussel richness and locating rare species (Metcalfe-Smith *et al.* 2000, Vaughn and Spooner 2004) and are more cost effective when surveys of large areas are needed as compared with quadrat methods.

Vaughn (1998) reported a mean abundance for all 31 sites of 14.4 mussels/h and a mean richness of 3.3 species per site. Current abundance and richness across all 31 sites were 38.0/h and 5.2 species per site, significantly greater than reported by Vaughn ($P = 0.002$ and $P = 0.001$, respectively). Mean sampling time between the two surveys was not significantly different ($P = 0.65$) with 46.8 min in this survey vs.

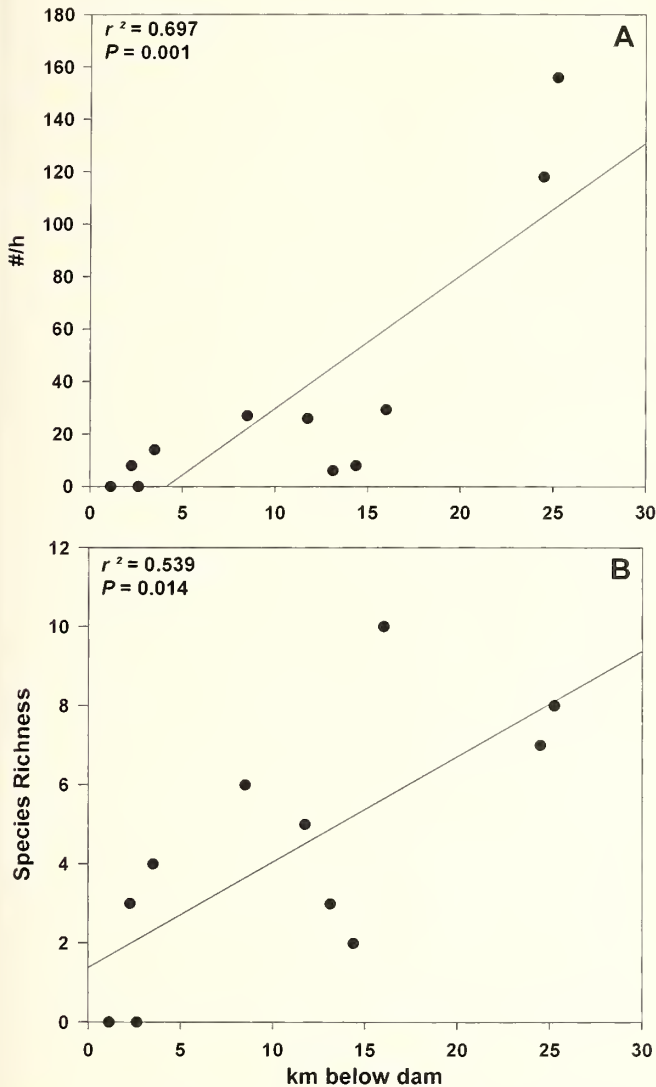


Figure 4. A, Distance from the dam vs. mussel abundance (#/h). B, richness in Verdigris River, Oklahoma for sites below Lake Oologah dam. Coefficients of determination and significance levels are shown.

49.8 min in Vaughn (1998). To evaluate the extent to which the increase in richness resulted from locating more mussels overall, abundance vs. richness curves were prepared from both studies (Fig. 5). These curves were linearized by log-transforming abundance to facilitate statistical analysis. There was no significant difference between studies in the regression coefficient (36.7 for the present study vs. 65.7 for the Vaughn study, $P > 0.05$) or elevation ($P > 0.05$), indicating that mussel abundance explained a similar degree of variation in taxonomic richness in both studies. Thus the greater taxa richness in the present study appears to be ex-

plained by our finding a greater number of mussels during the timed searches.

Given the semi-quantitative sampling employed in both surveys, care should be taken not to over-interpret these data. Strayer (1999) found low statistical power for detecting population declines when using presence/absence techniques; therefore, these results should at a minimum support the need for more quantitative techniques throughout the study area. Miller and Obermeyer (1997) and Miller and Lynott (2006) reported an increase in 10 different species in the Kansas portion of the Verdigris River relative to 1991 levels, using quadrat methods. They attribute this increase to improvements in habitat quality, namely reduction in pollution, increase in fish hosts, and lack of severe drought. These same factors may be working to improve native mussel populations in the Verdigris River of Oklahoma.

The detrimental effects of zebra mussels on native mussel communities are well documented (Burlakova *et al.* 2000, Martel *et al.* 2001, and Schloesser *et al.* 2006) although we found no difference in mussel abundances between sites upstream of Oologah Lake and sites downstream of the dam which are infested with the mussels. However, two relatively "good" sites greater than 20 km from the dam may have influenced these analyses. A number of native mussels were found to have byssal threads on their valves, indicating some degree of zebra mussel settling. It is possible that zebra mussel colonization of native mussels occurs during the spring, but the attached *Dreissena polymorpha* may be eliminated as water temperatures increase through the summer. The impoundment at Oologah Lake was designed for hypolimnetic releases, meaning if water releases occurred during summer, downstream habitats would receive cooler water. However, from August to November of 2006, there were no releases from the reservoir. Without this influence, it is reasonable that water temperature in these downstream reaches of the Verdigris River was similar to that in other streams in the area and approached 30 °C in mid summer. This temperature may be lethal to zebra mussels (Karatayev *et al.* 1998, Matthews and McMahon 1999, Elderkin and Klerks 2005) while unionids may be slightly more tolerant (Polhill and Dimock 1996). Additionally, monitoring of zebra mussel densities in Oologah Lake indicated a significant die-off beginning in late June 2006. Adult zebra mussel densities declined from nearly 150,000 /m² to <4,500 /m² from late June to September 2006 (Chad Boeckman, unpubl. data). Temperature-induced seasonal die-offs of zebra mussels in the Verdigris River may mean that zebra mussel fouling of native mussels does not reach high enough numbers to cause a significant effect. Other studies have reported mortality of unionids due to zebra mussel infestation within 2 to 8 years after initial zebra mussel colonization (Schloesser *et al.* 1996, 2006, Ricciardi *et al.* 1998, Schloesser and Masteller 1999).

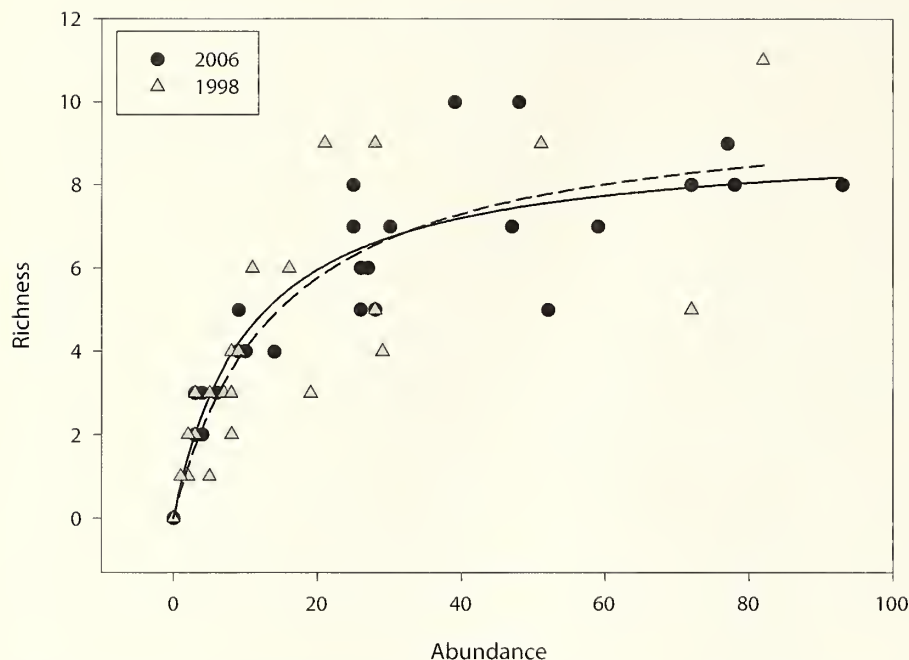


Figure 5. Richness (# of species/site) vs. abundance (total # of mussels found at that site) curves for the Vaughn (1998) survey (dashed line) and the current survey (solid line). For statistical analysis, these curves were linearized by log-transforming abundance. The resulting regression equations were $y = 4.332x + 0.1135$ for the present study and $y = 4.284x + 0.0257$ for Vaughn (1998).

Zebra mussels were first reported in Oologah Lake in June 2003 (Laney 2005), with numbers increasing steadily since that time. Negative effects on unionids due to zebra mussel colonization may still happen, if a cooler summer were to occur.

Several studies have shown that zebra mussels and native mussels can co-exist in habitats with fluctuating water depth, potential wave action, and substrate soft enough to allow native mussels to bury (Schloesser *et al.* 1997, Nichols and Amberg 1999, Bowers and De Szalay 2004, Strayer and Malcom 2007). The habitat below Oologah Lake does have some of these characteristics.

A potentially confounding factor in determining the effect of zebra mussels on unionid mussels is the influence of the Oologah Lake dam. The effects of impoundments on native mussel communities have been well established (Bogan 1993, Vaughn and Taylor 1999, Bednarek 2001, Sethi *et al.* 2004). For example, Vaughn and Taylor (1999) described a reduction in native mussel populations below an impoundment and found 20 km was needed for these populations to recover to pre-impoundment levels. In the current survey, mussel abundance downstream from the reservoir was positively correlated with distance from the dam. However, this relationship may have resulted from two sites

(greater than 20 km from the dam) that harbored the greatest abundance of all 31 sites surveyed. Downstream sites less than 20 km from the dam generally had poor or less than average abundance, and two sites immediately downstream from the dam had no live mussels at all. Taxonomic richness for downstream sites was also positively correlated with distance from the dam although less distance from the dam was needed to “recover” as compared with abundance.

While it appears that zebra mussels are currently having little effect on native mussel richness and abundance below Oologah Lake, the consequences of long-term zebra mussel colonization on native mussels in this reach of the river are still unknown. For this reason, conservation efforts such as periodic defouling or propagation and reintroduction (Hallac and Marsden 2001, Strayer *et al.* 2004) to sites above Oologah Lake should be directed at species of special interest (and native mussels in general) that are currently located below Oologah Lake. *Quadrula*

cylindrica should be a high priority for such efforts given its rather limited distribution in the Verdigris River (Obermeyer *et al.* 1997a, 1997b), the impoundment upstream and dredging activity downstream, and the relatively limited dispersal of its fish hosts.

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